STEALTH, THE END OF DEDICATED ELECTRONIC ATTACK AIRCRAFT

A MONOGRAPH
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ABSTRACT

STEALTH, THE END OF DEDICATED ELECTRONIC ATTACK AIRCRAFT? by Major Michael F. Hake, USAF, 57 pages.

The importance of protecting limited aircraft assets cannot be overstated. The loss of a modern aircraft entails the probable loss of highly trained and experienced crews that took years to develop. Furthermore, if a target is missed because of defensive reactions to radar-guided weapons, the sortie is lost and the target will have to be attacked again, draining valuable resources from the war effort and risking the attack package all over again. Therefore, the jamming of early warning, ground-control intercept, and acquisition radars maximizes the success of strike packages by creating significant confusion and friction inside the command and control system of an adversary by denying critical intelligence on aircraft routes, altitudes, and timing. This friction slows an adversary's ability to respond to aerial attacks and therefore contributes directly to the preservation of combat power - experienced combat crews and aircraft.

Joint Publication 3-01.4 defines Electronic Warfare (EW) as "any military action involving the use of electromagnetic energy and directed energy to control the electromagnetic spectrum or to attack the enemy." EW is further divided into three subcategories: Electronic Attack (EA), Electronic Protect (EP), and Electronic Warfare Support (ES). All three of these subdivisions are critical to the creation of synergistic effects in the modern electromagnetic battlefield. The Department of Defense's decision to retire the EF-111A and create four EA-6B Joint Expeditionary Squadrons within the Navy highlights a significant shift in the EA philosophy of the Department of Defense.

The proliferation of modern surface-to-air missile systems, early-warning and ground-controlled intercept radars, and the abundant number of anti-aircraft artillery weapon systems requires the maintenance of a robust EA capability. Though the stealthy B-2, F-117, and F-22, garner a great deal of attention, these aircraft will remain a relatively small percentage of the USAF and USN fighter/bomber force due to cost. Thus, the United States will continue to need an EA platform that can provide support to non-stealthy aircraft in a medium-to-high threat environment in a joint atmosphere. Furthermore, the possibility of breakthroughs in radar and computer technologies may require retention of the Prowler as a national asset to retain flexibility and freedom of action. This monograph assessed whether or not strategic reliance on aircraft stealth technology as a force multiplier in the medium-to-high threat integrated air defense environment spells the end for the EA-6B Prowler's Electronic Attack mission. Research indicated that current and future force structure plans necessitate the continuation and modernization of the EA-6B prowler as well as acquisition of a follow-on platform due to the age of the EA-6B.

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Introduction

"We cannot expect the enemy to oblige by planning his wars to suit our weapons; we must plan our weapons to fight war where, when and how the enemy chooses."[1]

Vice Admiral Charles Turner Joy

History has repeatedly demonstrated man's ability to develop countermeasures to new weapon systems. The birth of radar reflected this trend, in that radar was developed to counter a growing air threat. The accurate detection of hostile formations in bad weather or at night became a practical reality and formed the cornerstone of modern air defense systems.[2] Changes in radar technology resulted in the development of new countermeasures, which in turn led to the necessity of developing more advanced radar technologies. Hence, the cyclic history of radar development and radar countermeasures demonstrates the driving nature of technological improvements upon the development of electronic warfare doctrine and equipment.

The British were the first to develop an integrated air defense system (IADS) during the 1930's by building radar sites along their eastern coastline in order to provide early warning of air attacks originating from continental Europe.[3] During World War II, the information provided by these sites was correlated by operations centers to develop an integrated air picture enabling Fighter Command's limited assets to gain the greatest effects against the German Luftwaffe during the Battle of Britain. Moreover, the history of World War II documents the progressive development of electronic combat doctrine and new equipment, such as chaff and radar jammers by the Allies in order to suppress German radar sites during aerial attacks against Germany. The purpose of the suppression of German radar systems was to mitigate the effectiveness of radar directed anti-aircraft artillery (AAA). Thus, World War II gave birth to modern electronic warfare. The requirement to protect aircraft against radar directed weapon systems has grown exponentially with the development and employment of vast numbers of modern radar directed surface-to-air missile (SAM) systems and advancements in radar-guided anti-aircraft artillery. Most recently,

Operation Desert Storm witnessed the invaluable contribution of dedicated electronic attack aircraft in the skies over Iraq.

The Desert Storm aerial campaign was designed to gain air superiority as quickly as possible to permit unimpeded Coalition air and ground operations throughout the theater. Iraq possessed the most modern and sophisticated integrated air defense system the US has confronted to date. Coalition forces faced over 600 SAM units, including Soviet SA-2, SA-3, SA-6, and SA-8; the Chinese HN-5; the French/German Roland 2; and 10,000 anti-aircraft artillery pieces including radar controlled 57-, 85-, 100-, 130-mm guns and ZSU-23-4 systems.[4] This integrated air defense system was generally employed in accordance with Soviet doctrine. The Coalition countered by employing NATO doctrine to disrupt and destroy the Iraqi IADS, which had been developed based on experience against Soviet systems gained from operations over North Vietnam, recent Middle East conflicts, and the US raid against Libya in 1986.

The ultimate success of the offensive electronic combat campaign resulted in only 10 of the 38 Coalition aircraft lost during Desert Storm damaged or destroyed by radar-guided SAMs.[5] Lieutenant General Horner, Commander USCENTAF during Operation Desert Storm, stressed in early February 1991 that American support for the war depended in large measure on the ability to operate "with less than anticipated" losses of human lives among Coalition airmen, soldiers, sailors, and Marines.[6] The presence of EF-111A and EA-6B tactical radar jammers contributed significantly to the achievement of that objective. By the time Desert Storm ended, the Coalition's loss rate was about one fixed-wing aircraft per 1800 combat sorties.[7] This loss rate was 4.7 times lower than experienced by the US over North Vietnam from January to December 1967 and some 14 times lower than experienced during Linebacker II operations at the end of US involvement in December 1972.[8] The low loss rates in Desert Storm stemmed from US electronic superiority and the decision to bomb from medium altitude after the first week. The effectiveness of tactical radar jamming against radar-guided SAMs and AAA allowed effective medium altitude operations to be

employed, reducing the risk of Coalition aircraft to infrared SAM systems and small caliber AAA encountered at lower altitudes.

The importance of protecting limited aircraft assets can not be overstated. The loss of a modern aircraft entails the probable loss of a highly trained and experienced crew that took years to develop. Furthermore, if a target is missed because of friendly threat reactions to enemy radar-guided weapons, the sortie is lost and the target will have to be attacked again, draining valuable resources from the war effort and risking attack aircraft all over again. Therefore, the jamming of Iraqi early warning, ground-control intercept, and acquisition radars maximized the success of strike packages by creating significant confusion and friction inside the Iraqi command and control system by denying them critical intelligence on Coalition aircraft routes, altitudes, and timing. This slowed their ability to defend against Coalition attacks and therefore contributed directly to the preservation of experienced combat crews and limited assets.

The proliferation of modern surface-to-air missile systems, early-warning and ground-controlled intercept radars, and the abundant number of anti-aircraft artillery weapon systems, requires the maintenance of a robust Electronic Attack (EA) capability. Even though the stealthy B-2, F-117, and F-22, garner a great deal of attention, these aircraft will remain a relatively small percentage of the USAF and USN fighter/bomber force due to cost. Thus, the United States will continue to need an EA platform that can provide support to non-stealthy aircraft in a medium-to-high threat environment in a joint atmosphere. Furthermore, the possibility of breakthroughs in radar and computer technologies may require retention of the Prowler as a national asset to support stealth-based aircraft.

In December 1994, the Department of Defense decided to retire the EF-111A, to rely upon the Navy's EA-6B for radar jamming support during contingency operations, and to integrate the radar jamming mission as a joint effort.[9] The requirement to examine the military necessity of maintaining a radar jamming capability is of the highest importance in view of future fiscal constraints that might question the need for maintaining the EA-6B and the increased reliance the

US is placing on stealth technology for aircraft protection. The purpose of this monograph is to answer the question: Does strategic reliance on aircraft stealth technology as a force multiplier in the medium-to-high threat integrated air defense environment spell the end for the EA-6B Prowler Electronic Attack mission? This monograph will highlight the historical development of electronic warfare, explore the necessity for retaining the Electronic Attack mission, and attempt to determine whether or not the tactical radar jamming mission will be necessary to successfully support future US military operations in the face of a medium-to-high threat integrated air defense system. The research materials used to address this question came from open sources such as books, magazines, and papers.

Five questions will be answered in order to determine whether or not the EA-6B Prowler mission is still required by the US in light of the acquisition stealthy aircraft. First, what is stealth technology? Second, what is the effectiveness of stealth technologies in protecting aircraft from current and forecasted radar threats? Third, would execution of the Prowler's mission enhance, harm, or prove irrelevant in supporting stealthy aircraft? Fourth, if future radar and computer technologies prove capable of detecting stealthy aircraft, can the Prowler provide effective electronic support to stealth aircraft? Finally, if the US acquires effective stealth aircraft, will the US still require the successful execution of the EA mission to conduct unilateral or coalition contingency operations?

Historical Development of Tactical Radar Jamming

"The unresting progress of mankind causes continual change in the weapons; and with that must come a continual change in the manner of fighting."

Rear Admiral Alfred Mahan[10]

The origins of electronic combat and radar theory can be traced to Heinrich Hertz of Germany who, in 1888, discovered electromagnetic energy could be propagated through the atmosphere at the speed of light.[11] The years following Hertz's discovery witnessed the spectacular development and growth of wireless radio technology as the first practical application of controlled electronic wave propagation through space. In turn, research into the properties and applications of electromagnetic waves opened the door to the realm of radar development and then the modern concept of electronic attack. Changes in radar technology continue to drive the development of new electronic countermeasures and result in the revision of existing electronic warfare doctrine of the time; an endless cycle of electronic countermeasure versus electronic counter-countermeasure. The art of electronic warfare is constantly trying to keep up with new technological breakthroughs and the ever-increasing sophistication of radar-guided threats.

At the turn of the twentieth century, scientists pursued research into the use of electromagnetic waves for the detection of objects. These devices would later be known as radar, meaning "radio detecting and ranging." One of the earliest examples of radar development can be traced to Christian Hulsmeyer, of Germany, who created the "Telemobiloscope" in 1904.[12] This device possessed a transmitter and receiver mounted side-by side that could detect ships crossing through its beam. This first attempt at a radar system relied on the interruption of a continuous wave form in order to detect the passage of a ship. While being able to detect the passage of a ship, the use of a continuous wave did not allow for range determination. Thus, while Hulsmeyer's system could detect ships or objects out to 3,000 meters, there was no way to determine whether the object was at 500, 1200, or 3,000 meters.[13]

Between World War I and World War II, the United States, Germany, and Great Britain, devoted significant effort and resources towards the development of an effective radar device. The two principal employment requirements for radar were foreseen as early warning of air and sea threats and to provide targeting information to naval guns and anti-aircraft weapons for increased accuracy and lethality.

In the United States, the US Naval Research Laboratory (NRL) began experiments with radio detection systems as early as 1922, using a continuous wave transmitter similar to that created by Hulsmeyer.[14] By 1934, the NRL refined this interference concept and technology to the point of being able to detect an aircraft at 50 miles.[15] Once again, however, the interference-based radar system notified an operator when an object was present, but was still unable to provide range or altitude. By 1936 NRL research efforts were achieving many breakthroughs in the development of ground and air based radar systems.

In April 1936, the NRL built its first pulsed radar, which was able to detect an aircraft at 10 miles and by June, the range increased to 38 miles.[16] Additionally, in April 1936, an experimental radar was installed on the destroyer USS Leary with a range of 20 miles.[17] By December 1939 the XAF Naval radar proved successful at detecting aircraft out to 100 miles and ships at 15 miles.[18] The SCR-268 coastal and anti-aircraft system became the first radar to go into production for the US Army in 1941.[19] The use of electronic pulses allowed for the determination of range and altitude, overcoming the deficiencies of continuous wave radar systems. Thus by 1941, the United States possessed an effective radar system capable of detecting surface and air threats and of providing targeting data.

In Germany, work on the development of radar gained impetus under the direction of Dr Rudolph Kuehnold in 1933.[20] By October 1934, the Germans had developed continuous wave radar, which was able to detect ships at 7 miles. By the spring of 1936, the Germans had also developed a pulsed radar, which became known as the Freya.[21] At the commencement of World War II, the Germans possessed about 100 Freyas and employed them as the backbone of their early

warning system.[22] In addition to the Freya, a new radar known as the Wuerzburg entered service in the summer of 1940 and would later be used to direct AAA, searchlights, and night fighters, as well as a height finder for the Freya.[23]

By June of 1935, Great Britain was developing pulsed radar that allowed for the detection of aircraft at 17 miles.[24] In March 1936, Britain's technological innovation resulted in the development of a radar system capable of detecting aircraft up to 75 miles.[25] The British grasped the significance of using radar to defend against aerial attack and correspondingly built an integrated coastal radar network. This radar network became known as the Home Chain and was tied into Fighter Command prior to World War II.[26]

Radar was an entirely new concept in military technology at the commencement of World War II. While the stronger side generally wins in combat, history is replete with examples of the inferior force gaining a crucial advantage and defeating the stronger opponent. Radar provides the ability to detect and target an enemy aerial force enabling a defender to mass at the crucial time and place. The Battle of Britain clearly demonstrated the tactical advantage radar gave to the numerically inferior Fighter Command in combating the German Luftwaffe. The Battle of Britain is also significant in that it gave birth to the concept of electronic attack and the development of radar jammers, chaff, and deception.

The Battle of Britain began in July of 1940 with the German Luftwaffe emphasizing offensive counterair missions.[27] As part of their plan to gain air superiority, the German's primary targets were the Royal Air Force's fighters, air bases and defenses, and coastal radar sites. One of the initial attempts by Germany to degrade Britain's integrated air defense system was the employment of a radar jammer on Mount Couple, code named "Breslau," to jam Britain's coastal radars around Calais.[28] The lack of sufficient numbers of Breslau jammers and the anti-jamming measures possessed by the British radar systems combined to nullify the German effort.[29] While engaged against the Germans in the summer of 1940, the British recognized the need to collect electronic intelligence on German radar systems to be able to successfully counter Axis technology

prior to launching their own strategic bombardment campaign. A limited number of specially modified British Hallicrafter S-27 aircraft were built to perform this key collection mission.[30] These aircraft patrolled German occupied territories with highly sensitive receivers in order to collect technical data for exploitation.

Great Britain exploited the collected electronic intelligence on German radar systems by developing the first electronic attack system designed to spoof enemy radars into indicating multiple false targets. This electronic countermeasure, code-named "Moonshine," was initially carried aboard a Hallicrafter S-27 on August 6, 1942.[31] Since the British would not be able to directly witness the affects of Moonshine against German radars, the British had to rely on German responses as an indicator of their success. British radar systems observed the success of Moonshine when German fighters were repeatedly launched against the ghost armada during dry runs conducted at night.[32] Since the Germans possessed visual observation posts to give warning of impending Allied attacks, Moonshine was only effective at night or under adverse weather conditions when Allied aircraft could not be visually detected.[33]

In December of 1942, the British introduced the Mandrel and Tinsel jammers to counter the Freya and Wasserman radars.[34] In January 1943, however, one month after employing the jammers, a British monitoring station picked up a Freya radar operating outside its previously known technical parameters requiring the British to update their jammers.[35] Until the end of the war, the Germans and the British would continue to increase their frequency diversity in an attempt to counter their adversary's countermeasures in an endless electronic countermeasures (ECM)--electronic counter-countermeasures (ECCM) cycle.

Operation Overlord is well known in terms of the land campaign, however the significant contributions of the electronic campaign are not as well known. By the evening of June 5, 1944, 76 of the 92 German coastal radar sites along the French and Belgium coasts had been attacked by Allied airpower.[36] In conjunction with the Allied invasion, two electronic attack operations, code named TAXABLE and GLIMMER, were launched in order to deceive the Germans as to the

direction and orientation of the Allied invasion.[37] GLIMMER aimed for Le Havre while TAXABLE focused on the area around Dunkirk, Calais, and Boulogne.[38] Allied bombers established a small rectangular racetrack at low altitude and dropped chaff on the inbound leg to simulate the approach of an Allied convoy at approximately seven knots. These actions were coordinated with a small fleet of patrol craft that proceeded to within ten miles of the coast and anchored reflective balloons to simulate ships and played tapes simulating the sound effects of a fleet launching landing craft.[39] Only weak jamming was used to confuse German operators in order to allow the Germans to paint a radar picture indicating the advance of an Allied naval force.[40] Additionally, the RAF flew Lancasters and Flying Fortresses equipped with communications jamming equipment which prevented effective ground control of German night fighters being sent to investigate the ghost armada.[41] This represented the first integration and synchronization of electronic attack assets in support of a large-scale deception plan. Winston Churchill best expressed the success of electronic countermeasure used in the Normandy invasion when he said:

> "Our deceptive measures before and after D-Day, were planned to provoke confusion of ideas, their success was admirable and the consequences long withstood during the battle."[42]

By the beginning of 1945, the Allies dominated the electromagnetic spectrum using jammers and chaff.

The cost of the US electronic countermeasures program was estimated at $220,195,000, while the assets produced by the program were credited with saving 800 heavy bombers at a replacement cost of $350,000,000.[43] The true success of the electronic countermeasures program, however, cannot be measured in terms of dollars. The US electronic warfare program was credited with saving over 800 bomber crews whose experience and skills took tremendous resources and time to develop under wartime conditions.[44] Furthermore, Dr Fred Whipple, chaff consultant for US military, pointed out that it is often overlooked that chaff and jammers significantly contributed to mission success.[45] These two electronic countermeasures allowed bombers to penetrate at lower

altitudes resulting in greater accuracy in striking targets. This increase in accuracy significantly reduced the number of targets needing to be reattacked and correspondingly decreased the risk of losing experienced aircrews and limited aircraft.

The principal target of Allied jamming efforts during World War II were the fire control radars of ground based anti-aircraft gun batteries such as the German Wuerzburg and Mannheim as well as the Japanese Tachi 1, 2, 3, and Mark IV Models 1, 2, and 3.[46] A World War II study, conducted in October 1943, on the effectiveness of jammers in reducing aircraft lost to AAA was conclusive—in 3 out of 4 aerial attacks electronic countermeasures resulted in significant reductions in losses.[47] Furthermore, during the bombing of Bremen by the US 8th Air Force, Allied losses decreased by 50 percent as a result of employing the radar jammer "Carpet."[48]

After the end of hostilities in Europe and the Pacific, the United States demobilized and mothballed most of its electronic combat infrastructure.[49] Much of the equipment was sold as surplus and most of the experienced research and development staff moved onto the private sector where radar was being developed to support the emerging civil aviation sector. However, five short years after the end of World War II, the United States found itself embroiled in another conflict on the Korean peninsula.

While the Korean War was not waged on the same scale as World War II, the electronic warfare tactics and techniques of World War II were found to still be applicable. By the summer of 1952, night flying B-29s were being subjected to accurate radar-controlled AAA and limited fighter interceptions.[50] World War II jamming equipment was brought out of storage, updated to new frequencies, and flown as in the previous war. The successful employment of these countermeasure systems reduced B-29 losses by about two-thirds of what might have occurred had they not been employed.[51] The Korean Conflict proved once again that aircraft penetrating enemy territory defended by radar directed weapon systems, require electronic combat support assets to survive and to successfully accomplish the mission.

After the Korean Conflict, two aspects of the early 1950s initially hindered further development of electronic countermeasures for aircraft: the advent of the jet age, with its high speed and high altitude capabilities; and the Eisenhower Administration's defense policies which emphasized strategic nuclear capabilities over the tactical forces.[52] The high speed and improved high altitude performance of modern jet aircraft fostered the belief that aircraft could outperform threats and survive. This belief is similar to the ones held in the United States and Germany during the 1930s. During the 1930s, the development of all metal, multi-engine bombers that could out perform the fighters then in existence led both the United States and Germany to believe that their bomber force would successfully reach the target without support. This concept was proven false during World War II when bombers suffered tremendous losses in the face of well-orchestrated integrated air defense systems using radar, anti-aircraft artillery, and fighters. The loss of hundreds of German ME-110s and Stukas, as well as American B-17s proved that bombers needed electronic support to successfully accomplish their mission. The second factor hindering the development of new electronic attack equipment were budget cuts of the Tactical Air Forces in order to support Strategic Air Forces. These budget limitations hindered research and development efforts to develop smaller cooling systems and power systems that would not penalize weight-sensitive tactical aircraft.[53]

By the late 1950s however, Soviet development and fielding of the SA-1 and SA-2 to counter the West's nuclear capable bombers reawakened interest in the use of electronic countermeasures.[54] The Soviets recognized the importance of electronic superiority to successful combat operations and codified it in their doctrine of Radio-Electronic Combat (REC). REC is defined in the Sovetskaya Voyennaya Ensiklopediya (Soviet Military Encyclopedia) as:

> "the set of measures performed for reconnaissance of the electronic material and systems of the enemy and their subsequent electronic neutralization as well as the friendly measures performed from the electronic protection of friendly electronic material and systems. Radio electronic combat measures are carried out in conjunction with the destruction of electronic material, principally by weapons that home on emissions."[55]

The shoot down of a high altitude U-2 reconnaissance aircraft over the Soviet Union on May 1,

1960 by an SA-2 proved speed and height could no longer be regarded as the primary penetration aids for the strategic bomber force, and gave new impetus to US research and development efforts in electronic warfare.[56] This incident proved once again that aircraft penetrating a radar based defense network require electronic support. Finally, this example demonstrates that increased reliance upon the electromagnetic spectrum makes the control and protection of this facet of military technology a critical component to the success of modern military operations.

While the US first became aware of the Soviet SA-2 in 1953, and suffered its first loss to this modern surface-to-air missile in 1960, the effectiveness of the new surface-to-air weapon system was to be displayed in the skies over North Vietnam five years later.[57] Aircrews confronted a sophisticated air defense network comprised of integrated early warning radars, surface-to-air missile systems, and fighters. The rising loss of US aircraft to North Vietnamese radar controlled air defenses gave birth to the modern concept of Suppression of Enemy Air Defenses (SEAD).[58]

The loss of an F-4C tactical fighter on 24 July 1965 to a SA-2 Guideline surface-to-air missile over North Vietnam ushered in a new era of electronic warfare.[59] By the end of 1965 the Air Force was forced to review its tactics and strategy as aircraft losses climbed to about 160, with most of the losses being credited to SA-2 missiles.[60] The Pacific Air Forces enemy order of battle for Southeast Asia included 14.5-, 37-, 57-, 85-, and 100-mm gun batteries with an effective altitude coverage up to 45,000 feet.[61] Furthermore, by February 1966 between 22 and 24 SA-2 systems were operational in North Vietnam.[62] Unfortunately these sites were placed off limits to attack for US bombing missions for fear of killing Soviet technicians who were helping to build the sites as well as training North Vietnamese to operate the systems.[63] By 1968, this political decision required the development of a standoff tactical radar jamming platform to counter the growing radar directed threats in North Vietnam estimated at 5,000 to 7,000 AAA pieces and about 150 SAM sites.[64]

In an attempt to mitigate the threat posed by radar directed anti-aircraft artillery and SA-2s, the US Air Force retrofitted the B-66C Destroyer bomber as a standoff jamming platform.[65] EB-

66s were operated from Takli and Korat, Thailand from the late 1960's through Linebacker II in December 1972.[66] The EB-66s were regarded as an interim solution and scheduled for retirement following the withdrawal of forces from Southeast Asia in the mid-1970s.[67] The development of a replacement for the EB-66 began in the late 1960s. During Linebacker II the Navy's newest radar jamming platform, the EA-6B, employing the ALQ-99F Tactical Jamming System, made its first tactical appearance.[68] The USAF later considered acquiring the Navy's new EA-6B as a replacement for the EB-66, but excluded it on the basis of inadequate flight performance.[69] While the USAF dismissed the EA-6B, its ALQ-99F Tactical Jamming System was recognized as highly capable and desirable. After evaluating multiple aircraft, the high-performance F-111A bomber was chosen to house the Air Force's new ALQ-99E. The future would witness the flight of the first prototype on March 10, 1977 and after subsequent modifications the first operational EF-111A Raven was delivered to the USAF on June 19, 1981.[70] The Air Force would go on to acquire a total of 42 EF-111As by late 1985.[71]

By the end of the Vietnam War, standoff jamming aircraft, self-protection pods, and chaff corridors, dominated Linebacker II.[72] The effective integration of attackers and electronic support aircraft into packages directly contributed to significant reductions in aircrew and aircraft losses to radar-guided missiles:

> "During the course of the air war over North Vietnam there had been a steady drop in the effectiveness of the SA-2 missile, as various countermeasures took effect. When it was first used on a large scale, in 1965, the SA-2 destroyed about ten fighter-bombers for an estimated 150 Guidelines launched: an average of one kill for every fifteen missiles. By November 1968 one aircraft was shot down for every 48 missiles fired. During Linebacker II [1972] one aircraft was destroyed for roughly every 50 Guidelines fired."[73]

By the end of the Vietnam conflict, the United States Air Force developed a thorough understanding of the modern electronic battlefield and refined its electronic warfare doctrine, equipment, and tactics to counter the growing radar threat environment. The lessons learned over North Vietnam were to be proven true once again in the Middle East in the fall of 1973.

The Yom Kippur War of October 1973 demonstrated once again that air operations cannot be conducted in an environment where an integrated air defense network has full use of its communications, surveillance, and fire control systems. Israel's inability to counter Egyptian and Syrian air defenses and achieve spectrum superiority resulted in unacceptable losses during the initial stages of the war.[74] Israel's high losses clearly demonstrated the lethality of modern IADS. The weapons and tactics employed by both sides during the Yom Kippur War were the result of the lessons learned, or not learned, from the 1967 War.

As a consequence of the humiliating defeat suffered earlier during the 1967 War, Egyptian and Syrian military forces embarked on a rapid modernization of their air defense systems. With the assistance of Soviet advisors and equipment both country's developed an integrated air defense system.[75] By 1973, Egypt and Syria had developed an air defense force consisting of approximately 180 radar sites, 400 radars, 50 control centers, and 200,000 trained personnel.[76]

In contrast to her Arab neighbors, Israel's sweeping victory in 1967 continued a string of victories going back to 1936 causing a failure to conduct a critical analysis of internal failures or determine significant areas for improvement.[77] Israel tended to treat Arab weaknesses as cultural and almost inevitable in the Arab approach to war, rather than poor organization and leadership.[78] The Israeli Defense Force would pay a heavy price for their overconfidence as Egypt, led by President Anwar Sadat, reorganized its military structures, rearmed, and retrained with the assistance of the Soviet Union.

Though Israel was aware of the existence of the new SA-6 SAM and ZSU-23-4 radar-directed anti-aircraft artillery gun system, they were not aware of the technological changes these systems possessed to include expanded frequency ranges.[79] Therefore, Israeli electronic warfare equipment was not designed to counter these threats.[80] Furthermore, Israel did not possess the financial resources to develop and maintain a dedicated stand-off radar jamming capability such as the EB-66 or EA-6B.[81] The lack of a dedicated stand-off radar capability resulted in Israeli losses mounting so rapidly over the Golan Heights and Sinai that on 6 Oct the Israeli Air Force (IAF)

stood down to reassess its strategy and tactics in light of the integrated air umbrella possessed by the Arabs.[82]

The IAF lost 50 aircraft in the first 3 days of the war with total losses rising to 102 by the end of the war, representing nearly 37 percent of Israel's pre-war assets.[83] Two events finally turned the tide of the air war in favor of Israel: massive resupply by the US to include new self-protection pods and retuned radar warning receivers with the capability to display SA-6 indications;[84] and a successful Israeli ground counterattack which overran and destroyed SAM sites. In contrast to the 1967 war, an Israeli commission reviewed the conduct of the 1973 war and made major recommendations for change.[85]

Israeli losses re-energized the United States military into rethinking the priority needed to fight and win in the modern electronic battlefield. The Yom Kippur War could be viewed as a proxy war between US and USSR technology. In contrast to Israel, however, the US possessed the financial resources necessary to develop and maintain dedicated electronic combat aircraft such as the EA-6B, EF-111A, and F-4G to counter the growing electronic threat. The necessity to develop and maintain dedicated Electronic Attack aircraft was viewed as necessary in light of the US orientation on a war in central Europe. The possession of dedicated electronic combat aircraft was seen as key to NATO's ability to gain and maintain air superiority. Chairman of the Joint Chiefs of Staff, Admiral Thomas Moorer noted during a 1975 Senate procurement hearing:

> "...the classic doctrine that the priority of employment of air assets must be given to gaining and maintaining air superiority over the battlefield has been proven again. Today, gaining superiority includes defeating enemy SAMs in detail. Until enemy air defenses are degraded, any application of aerial firepower will be costly."[86]

The validity of this statement would be clearly demonstrated in the Beka'a Valley of Lebanon in 1982 and over Libya in 1986.

On June 6, 1982, Israel conducted a limited war, code named "Peace for Galilee," against Lebanon to secure its northern border from terrorist attacks.[87] During a two day SEAD campaign, the IAF completely destroyed the Syrian IADS consisting of SA-2s, SA-3s, SA-6s, and ZSU-23-4s,

targeting approximately 19 Syrian missile batteries in two hours on the first day.[88] The exceptional effectiveness of the SEAD operations resulted in air superiority and the loss of only one aircraft and two helicopters during the entire "Peace for Galilee" campaign.[89] As a result of air superiority over the SAM threat, the IAF was able to devote an extraordinary percentage of its total sorties to the attack mission.[90]

Having learned their lessons in the 1973 War, the Israelis successfully synchronized both their air and ground forces to effectively suppress Syrian batteries. Unmanned aerial vehicles were used to stimulate the SAM environment and cause Syrians to turn on their target tracking radars.[91] Electronic intelligence (ELINT) collection platforms were then used to detect, identify and locate the target tracking radars (TTRs).[92] The collection of this intelligence allowed the Israelis to map out Syria's electronic order of battle.[93] Targeting data was then passed to waiting Israeli strike aircraft. Furthermore, Israeli Army forces assisted with artillery and rocket attacks and successfully inserted a commando team tasked with destroying a key air defense communications center.[94] As a consequence of this conflict, Israel devoted tremendous effort to improving its edge over Syria in every aspect of electronic warfare, to include UAVs and enhanced electronics for their aircraft.[95] The US employed many of the Israeli lessons learned thirteen years later.

In April 1986, President Reagan ordered the USAF and USN to conduct strikes against Libya in retaliation for Libyan sponsored terrorism against Americans in West Germany.[96] The air plan for this operation was complex due to political restrictions and Libya's possession of a sophisticated Soviet designed air defense network composed of SA-2, SA-3, SA-6, and SA-8 missile systems.[97] The attack scheme used three EF-111As from RAF Upper Heyford and carrier based EA-6Bs to jam early warning, ground-control intercept, and acquisition radars to mask the ingress, attack, and egress of the strike packages attacking targets in the Tripoli and Benghazi areas.[98] As a result of this effective screen, the employment of high speed anti-radiation missiles (HARMs), and low-level profiles, no aircraft were lost to radar controlled threats. The experience

gained in packaging long-range strikes and the effective employment of electronic combat aircraft would be called upon again in 1990 when Iraq invaded Kuwait.

The Desert Storm aerial campaign was designed to gain air superiority as quickly as possible to permit unimpeded coalition air and ground operations. The first two systems to be targeted were the telecommunications/C3 systems and the strategic IADS radar sites, SAMS, and air defense control nodes.[99] Iraq possessed the most modern and sophisticated integrated air defense system the US has ever faced to date. Coalition forces faced over 600 SAM units including Soviet SA-2, SA-3, SA-6, and SA-8; the Chinese HN-5; the French/German Roland 2; and 10,000 anti-aircraft artillery pieces including radar controlled 57-, 85-, 100-, 130-mm guns and ZSU-23-4 systems.[100] This integrated air defense system was generally employed in accordance with Soviet doctrine. Thus, the coalition employed NATO doctrine to disrupt and destroy the Iraqi IADS, which in turn were developed based on experience against Soviet systems gained from operations over North Vietnam, recent Middle East conflicts, and the Libyan raid.

During the first night of the war, the coalition orchestrated a complex array of attacks: Army helicopters destroyed key border radar sites, Tomahawk cruise missiles attacked command and control nodes, and F-4Gs carrying HARMs in conjunction with EF-111As and EA-6Bs jammed and destroyed SAM radar sites.[101] In contrast to US policy in North Vietnam where SAM sites around Hanoi were off limits to attack, the coalition brought maximum firepower to bear against Iraqi command and control facilities and SAM sites around Baghdad to paralyze and destroy Iraq's ability to effectively respond against subsequent attacks.

The ultimate success of the offensive electronic combat campaign was proven because only 10 of the 38 coalition aircraft lost during Desert Storm were damaged or destroyed by radar-guided SAMs.[102] While no suppression activity can realistically eliminate unguided AAA or IR SAMS, the presence of dedicated tactical radar jamming was still required in the later phases of Desert Storm even after the IADS had been broken down. As Major Hewitt, F-16 pilot and SAAS graduate, quoted, "the Wild Weasels [F-4Gs] beat up on the enemy radar so bad that they

essentially stopped radiating; and they'd come up for 4 or 5 seconds at a time and shoot and go back down," leaving the missile unguided and useless.[103] While the SAM itself would have gone ballistic and presented no threat to coalition aircraft, the radar sweeps provided accurate information for barrage AAA fire against attacking aircraft. Only the presence of dedicated tactical radar jammers such as the EF-111A and EA-6B can suppress radar systems that come up for a very short period of time to deny accurate targeting data to AAA gun batteries.

General Horner stressed in early February 1991 that American support for the war depended in large measure on the ability to operate "with less than anticipated" losses of human lives among coalition airmen, soldiers, sailors, and Marines.[104] By the time Desert Storm ended, the coalition's loss rate was about one fixed-wing aircraft per 1800 combat sorties.[105] This loss rate was 4.7 times lower than that experienced by the US over North Vietnam from January to December 1967 and some 14 times lower than that experienced during Linebacker II operations at the end of US involvement in December 1972.[106] The low loss rate stemmed from US electronic combat superiority and the decision to bomb from medium altitude after the first week. Electronic combat mitigated the threat posed by SAMs and radar-guided AAA, while medium altitude tactics mitigated the risk of infrared SAM systems and small caliber AAA. The achievement of significant reductions in losses came with a price tag however, since aircraft such as the F-16 and F/A-18 achieved less accuracy as a result of employing principally unguided munitions at medium altitude.

According to Thomas Keaney, Professor of military strategy at the National War College, and Eliot Cohen, Professor of strategic studies at the Paul H. Nitze School of Advanced International Studies, the United States provided 96 percent of the Coalition's electronic warfare assets.[107] The US led SEAD campaign superbly orchestrated the employment of tactical radar jammers, drones, cruise missiles, stealth fighters, and deception, to gain surprise and enhance the mission effectiveness of ground attacks by coalition strike packages. In fact, the unavailability of electronic warfare assets became a reason to abort a mission. Of the 100 attack packages flown

from Incirlik AB, Turkey, only one was flown without such aircraft—the first night because these aircraft were not available due to political constraints of the Turkish government.[108]

EF-111As supported the very first wave of strikes against Iraq during Desert Storm and both the EF-111A and the EA-6B played crucial roles in denying radar-tracking data to SAMs and radar-guided AAA. Of the approximately 3,000 electronic warfare missions flown in Desert Storm, US air power conducted all but 80 of them.[109] As to the Ravens and Prowlers, eighteen EF-111As flew 1,105 combat missions from Taif Air Base, Saudi Arabia, twelve USMC EA-6Bs flew 504 combat missions, and twenty-seven USN EA-6Bs flew 1,126 combat missions.[110]

The support rendered by the EF-111A Raven and EA-6B Prowler was invaluable in saving highly trained and irreplaceable aircrew and valuable aircraft in Desert Storm just as their predecessors had in WW II, Korea, and Southeast Asia. Since the Gulf War, these two dedicated, tactical radar jamming platforms have continued their support of US objectives in Operations Southern Watch, Provide Comfort, and Deny Flight. In light of the increased sophistication and lethality of radar-guided threats and America's heavy reliance on non-stealth aircraft to project power, the need for a dedicated tactical radar jamming platform is greater than ever before.

Evolution of the Prowler as the Sole US Radar Jamming Platform

"To carry on a war, three things are necessary: money, money and yet more money."[111]

Gian Trivulzio to Louis XII of France, 1499

The EF-111A Raven airframe had a long and illustrious history. The Air Force selected the F-111A Aardvark as the airframe to become the newest dedicated radar jamming platform in the early 1970s. These all-weather supersonic bombers were originally produced in 1966 and 1967 and a few had the distinction of flying combat missions in the Vietnam War. After considerable debate during the mid-1970s, the Air Force contracted to develop its own tactical radar jamming aircraft versus purchasing the Navy's EA-6B because of the inability of the EA-6B to integrate itself within Air Force attack packages due to its slower speed.[112] The Raven went into service in 1981 with a total of 42 F-111As being modified into EF-111As.[113] The EF-111A is similar to the Prowler in that it uses the ALQ-99 Tactical Jamming System. The Raven carried 10 transmitters internally in a long canoe shaped fairing located underneath the front half of the airframe. The ability to carry ten transmitters internally reduced drag and accordingly added to the aircraft's range and loiter time. Furthermore, by carrying ten transmitters on every mission, the Raven was able to provide full frequency spectrum coverage in a three hundred and sixty-degree arc. Additionally, the Raven was operated by a two man crew, one pilot and one Electronic Warfare Officer (EWO). The Raven's ALQ-99E was much more automated than the one possessed by the Prowler allowing the single EWO to manage the increased workload. While not equipped with the AGM-88 HARM, the Raven was capable of speeds in excess if 1200 knots, which allowed it to be imbedded within any fighter or bomber attack package.[114]

On the other hand, the EA-6B Prowler is a twin engine, four seat, all weather electronic attack aircraft that is manned by one pilot and three Electronic Countermeasures Officers (ECMOs). The heart of the electronic system is the ALQ-99F Tactical Jamming System, which

allows the ECMOs to analyze, record, target, and jam enemy ground and airborne radars.[115] Initially, the Prowler had been configured as a two seat aircraft and designated the EA-6A, however do to the complexities of the ALQ-99F, the EA-6A was modified into the current four seat EA-6B. The EA-6B possesses four wing stations and one centerline station each capable of carrying either one jamming pod, or one high speed anti-radiation missile (AGM-88 HARM), or a fuel tank. The Prowler is a sub-sonic, non-afterburning jet aircraft with a top speed of 565 knots, but with a normal operation speed of 420 knots.[116] Additionally, the Prowler was upgraded with the USQ-113, which gives the aircraft a limited capability to jam tactical communications.[117]

Though the Raven and Prowler possessed unique capabilities, both airframes conducted similar missions. Three primary tactical jamming missions were performed: Stand-off Jamming, Close in Jamming, and Direct Support. Stand-off jamming is conducted over friendly territory and is used to screen the marshalling of forces or "heavies" such as AWACS, tankers, or reconnaissance aircraft. Close in jamming assists friendly attack packages with penetrations through a defended border. Direct support missions require the escorting EF-111A or EA-6B to cross into hostile territory with the attack package and suppress radar threats along the strikers' ingress and egress routes, as well as in the target area.

The greatest challenge to an attack package is the penetration of an integrated air defense system. An IADS is composed of multiple sites with a variety of sensor systems that all feed into a command and control network. The command and control network processes information and data from the various sites in order to develop a clear picture of the aerial environment and enemy intentions. The command center for a region then optimizes assigned defensive systems such as aircraft, SAMs, and AAA, to target and destroy incoming air threats. The use of early warning and acquisition radars to pass targeting data to target tracking radar systems protects TTRs from early detection and destruction by SEAD assets by allowing them to acquire targeting data without emitting.

Raven and Prowler jamming operations are generally oriented against early warning (EW), ground-control intercept (GCI), and acquisition (ACQ) radars. The degradation of EW, GCI, and ACQ radars forces target tracking radars (TTRs) into autonomous operations in order to identify and track attacking aircraft. When the TTRs radiate, they are targeted for destruction through the use of HARMs. Radar jamming and HARM operations need to be integrated to maximize combat effectiveness and contribute to mission success.

Operation Desert Storm demonstrated the outstanding effectiveness of joint operations in the performance of the suppression of enemy air defense mission. After Desert Storm, the EF-111A and EA-6B continued to provide its valuable force multiplier capability during subsequent "No Fly" operations as part of Operations Southern Watch and Provide Comfort. The Ravens flew from Incirlik AB, Turkey as well as Dhahran and Al Karj, Saudi Arabia, while the Prowlers performed their missions from carriers based in the Persian Gulf.

On the other hand, an incident during Operation Deny Flight illustrated what may happen when dedicated electronic support is not present. The shootdown of Captain Scott O'Grady's F-16 Fighting Falcon by a radar-guided surface-to-air missile during Operation Deny Flight highlights the need for a dedicated tactical radar jamming platform to support non-stealth aircraft. At the time of this incident, neither EF-111s nor EA-6Bs were on station to support Deny Flight operations.[118]

While stealthy aircraft provide unique capabilities, there are significant limits on the ability to employ the currently slow moving, black colored aircraft during daytime conditions. Furthermore, the acquisition of stealth aircraft has been few in number due to cost considerations, thus the US will continue to rely heavily on predominately non-stealth aircraft during contingency operations. Additionally, since future operations will probably integrate coalition partners, the US may need to maintain a tactical radar jamming system to enhance coalition air efforts.

However, fiscal constraints and a changing security environment resulted in reductions in force and the downsizing of military equipment during the late 20th Century. The end of the Cold War, symbolized by the destruction of the Berlin Wall, victory in Desert Storm in March 1991, and

the disappearance of a peer superpower threat, resulted in the political forces of the United States shifting their focus from a global perspective to a more domestic perspective. This change in policy outlook resulted in a diminishing budget for the US military and the necessity to find and implement cost saving measures.

Due to dwindling budgetary resources in the mid 1990s the Air Force needed to find ways to cut expenses in order to support readiness and combat capabilities. This requirement was not only being felt by the Air Force, but throughout the Department of Defense, so the decision to emphasize joint operations and eliminate duplication of efforts was helped along by Congressional inputs to the Department of Defense. In a landmark Senate floor speech in July 1992, Senator Sam Nunn (D-GA) called for the end to what he termed unnecessary and wasteful duplication within the Department of Defense.[119] Senator Nunn suggested that missions performed by two or more services be consolidated into a single mission.[120] He specifically named electronic combat aircraft.[121]

One area suggested for consolidation was in the realm of airborne electronic warfare. Both the United States Air Force and the United States Navy possessed a tactical radar jamming platform based on the ALQ-99 Tactical Jamming System. The Air Force possessed the EF-111A Raven, while the Navy and Marine Corps operated the EA-6B Prowler. While both aircraft possessed unique capabilities, some sources believed possession of these two airframes was redundant. After analyzing the issues, the Air Force decided to retire the EF-111A Raven. Despite the decision to retire the EF-111A, the importance of electronic combat support was not lost on the Air Force. Accordingly, the USAF in close coordination with the Navy, recommended to the Department of Defense to hand over the tactical radar jamming mission to the Navy's EA-6B Prowler.

In February 1993, Chairman of the Joint Chiefs of Staff General Colin Powell argued against retiring either aircraft and specifically recommended retaining both aircraft, citing complementary not duplicative capabilities that significantly benefit the Department of Defense.[122]

Not withstanding General Powell's recommendation, only two years prior, in May 1995, the congressionally mandated Commission on Roles and Missions of the Armed Forces revisited the issue of alleged redundancy in tactical electronic warfare aircraft.[123] The Commission suggested consolidation of several missions under a single platform or service. One recommendation called for the retirement of the EF-111A and shifting the entire mission, with increased funding, to the EA-6B.[124]

In December 1994, the Pentagon pre-empted the Roles and Missions of the Armed Forces Commission's recommendation by decisions incorporated in Program Budget Decisions (PBD) 752 and 753.[125] PBD 752 increased funding and manning appropriations for the Prowler by $656 million beginning in fiscal year 1996, while PBD 753 cut funding for the Raven by $1.482 billion through the end of fiscal Year 1997.[126] Over $1 billion of the EF-111A savings were obtained by terminating the System Improvement Program that would have upgraded the Raven's ALQ-99E Tactical Jamming System. The shifting of funds and the decision by top Air Force officials to retire the EF-111A left the EA-6B as the only electronic warfare option for Joint Suppression of Enemy Air Defense support for the US military.

The debate on retiring or maintaining the EF-111A was very energetic and focused on five key areas.[127] One argument favoring the continuance of the EA-6B was the fact that 127 EA-6Bs existed versus 40 EF-111As. The rationale was that quantity was important if a single platform was to support the operational requirements of two services. Secondly, the cost to operate the Prowler was calculated at $3,255 per flight hour versus $5,500 for the Raven. Third, both aircraft were in need of substantial upgrades to their software and hardware to be able to counter third and fourth generation anti-aircraft missile and AAA systems. To fund the upgrade of both aircraft, in a time of diminishing resources and no peer threat, was considered a poor return on the investment in light of newer emerging programs that needed funding. A fourth argument put forth was that the EA-6B possessed a small tactical communications jamming system called the USQ-113. This system gave the EA-6B a unique capability the EF-111A did not possess. Finally, some even

proposed that four aircrew members versus two was a tactical advantage due to increased situational awareness.

On the other hand, the primary arguments against the Prowler's selection as the sole tactical jamming platform centered around performance capabilities between the two aircraft and differences in employment doctrine and tactics between the USAF and USN.[128] As discussed before, the Prowler is not capable of supersonic flight, which is one of the principal tactics used in a high-threat environment by USAF attack aircraft. Furthermore, the Raven had slightly greater advantages in service ceiling, range, and endurance. Differences in the tactical employment of the two aircraft do exist; however, these differences never resulted in the inability to provide effective radar jamming. These two areas were evaluated before the decision to retire the EF-111A Raven was made and were not considered "show stoppers."[129]

In the end, three key facts weighed-in against the Raven. Historically, the F-111A was developed as a joint attack aircraft to replace the F-4 for the Navy and Air Force, but as the aircraft's size and weight increased it was no longer acceptable to the Navy because the aircraft could no longer operate from a carrier deck. Secondly, past decisions by the Air Force not to give HARM capability to the EF-111A, due to the existence of the F-4G, strictly limited the Raven's capability to radar jamming. Finally, the Air Force was promoting a concept that stealth aircraft required no outside electronic support to perform their mission, thus no reason existed to maintain the EF-111A. In the end, the EA-6B was the only viable choice, it could operate off carriers, the Navy wanted the mission, and the Navy possessed strictly non-stealth aircraft necessitating the continuation of carrier-based electronic support.

In response to the decision to retire the EF-111A, the Joint Requirements Oversight Council (JROC) recommended the creation of five joint-service EA-6B squadrons consisting of four aircraft each and that the EF-111A should be retired by the end of fiscal year 1997.[130] Ultimately only four Joint-Service Expeditionary Squadrons were established under the command of Navy, while being manned by both Air Force and Navy aircrew. When these units deploy in

support of a regional Commander in Chief (CINC), the Navy has responsibility for administrative support. This consolidation of a tactical mission was unique in military history in that service members from two separate services would train, fly, and fight together as a single unit and under the command of one service.

The retirement of the EF-111A was postponed until 30 Jun 98 as a result of the Navy's inability to reach the required number of operational EA-6B aircraft by 1 Oct 97 in accordance with the March 25, 1996 Memorandum of Agreement.[131] After a solid record of performance that included support to Operations Eldorado Canyon, Just Cause, Desert Storm, and Deny Flight to name a few, the venerable Raven was finally retired on 30 Jun 98. The EF-111A fleet is now mothballed at Davis Monthan AFB, Tucson, Arizona.

The protection of Air Force, Army, and Navy aviation assets from detection by early warning and acquisition radars now rests solely with the EA-6B. The requirement to examine the military necessity of maintaining a radar jamming capability is of the highest importance in view of future fiscal constraints that might question the need for maintaining the EA-6B and the increased reliance the US is placing on stealth technology for aircraft protection.

The answers to the following five questions are key in determining whether or not the EA-6B should be retained, limited resources should be dedicated for modernization of the Prowler fleet, and ultimately, does the United States need to invest in a follow-on radar jamming platform. First, what is stealth technology? Second, what is the effectiveness of stealth technologies in protecting aircraft from current and forecasted radar threats? Third, would execution of the Prowler's mission enhance, harm, or prove irrelevant in supporting stealthy aircraft? Fourth, if future radar and computer technologies prove capable of detecting stealthy aircraft, can the Prowler provide effective electronic support to stealth aircraft? Finally, if the US acquires effective stealth aircraft, will the US still require the successful execution of the EA mission to conduct unilateral or coalition contingency operations?

The World of Stealth

"Technology, as evidenced by new weapons and improved means of delivery, has a profound effect on how a nation's military forces plan to do their business."[132]

What is stealth technology?

The term "stealth" brings to mind invisibility exemplified by Star Trek's Klingon cloaking device that makes the starship invisible to all tracking systems. But even the Klingon cloaking device had one flaw, the device needed to be turned off in order to fire weapons. This science fiction example is significant because it highlights the possibility of imperfections in future technologies. While no known combination of technologies can make a manned aircraft completely invisible throughout the entire detection spectrum at all times, science continues to research new capabilities to achieve low observability. The term stealth applies to the entire range of design efforts to make an aircraft harder to detect and track through the incorporation of radar cross-section (RCS) reduction, infrared (IR) suppression, acoustic reduction, and visual camouflage. Of these four areas radar is the most critical, followed by infrared.[133] Stealth is a matter of degree, influenced by a long list of factors such as the platform's aspect to the radar, distance to the radar, the radar's frequency range, and weather.[134] In the end, stealth technology is a force multiplier that assists a commander by enhancing the achievement of surprise and increasing the survivability of limited aircrews and aircraft for future operations.

The term stealth not only applies to the technology of reducing the RCS, IR, acoustic, and visual signatures of an aircraft, but to the entire genre of aircraft characteristics specifically incorporated into aircraft design.[135] The United States Department of Defense is actively pursuing stealth technologies as seen by the operational employment of the F-117 and B-2, as well as acquisition of the new F-22 to maintain technological superiority over potential adversaries. The

promise of stealth technology is that aircraft will be able to safely operate in a hostile environment and thus be able to successfully execute its mission the first time without significant interference from an adversary's integrated air defense system; and perform this mission without dedicated escort and support aircraft. Through the integration of advanced technologies within aircraft design, decision-makers hope to enhance aircrew and aircraft survival and reduce the risk of political embarrassment resulting from failed military operations.[136]

Aircraft such as the F-15 Eagle and F-14 Tomcat were designed without much consideration to RCS or IR signature suppression.[137] The stealth property of achieving a low RCS is produced in three primary ways: airframe shape, airframe internal construction, and through the use of Radar Absorbing Material (RAM) coatings on the surface of the airframe.[138]

The idea of developing a radar avoiding aircraft came, ironically, from radar's inventor Sir Robert Watson-Watt who advocated the development of bombers with a low RCS.[139] The basic concept behind RCS-reduction design is to avoid boxy, angular airframes with parts joined at right angles; large, open, engine air intakes; and flat, nearly perpendicular surfaces such as planar radar antennas.[140] Externally mounted weapons and fuel tanks, and cockpits not protected by specially treated canopies are also well-known sources of radar reflectivity.[141] The requirement to forego external stores does have drawbacks. While eliminating external stores lowers drag, increases fuel efficiency and increases stealthiness, internal bomb bays result in either a smaller payload (as compared to the same aircraft with externally carried munitions) or a larger airframe.[142] The larger the airframe, the more complex the requirements to make it stealthy as seen by the cost of one B-2 approaching $800 million dollars.[143]

Radar Absorbent materials (RAM) absorb radar energy that comes into contact with an aircraft. The synergistic effects of combining a low RCS airframe and RAM significantly reduce an aircraft's detection by radar. Avoidance of polished, flat metal surfaces helps to reduce radar reflectivity.[144] The first endeavor to develop an aircraft with low radar reflectivity was attempted by Walter and Reimer Horten in 1943.[145] They built a twin engine flying wing

bomber/reconnaissance aircraft designed to absorb radar waves.[146] Due to the shortage of materials in wartime Germany, the Hortens used non-traditional materials to build a prototype in 1944 consisting of plywood wings with a sandwich center of charcoal.[147] This sandwich heralded the era of composite materials.

The next major advancement in RAM was the development of a paint that could be applied to surfaces. The first use of RAM paint can be traced back to the German Navy's use of RAM paint on the snorkel of U-boats to avoid detection during World War II.[148] Forty years later, the F-117A uses RAM paint, which integrates microballs of a ferrite compound in a special adhesive to minimize its radar reflectivity.[149] This RAM paint was developed by the Japanese and has been successfully used on the F-117A, TR-1, and the retired SR-71.[150] When radar energy strikes the RAM paint it generates a local electromagnetic field that absorbs the energy from the radar waves striking the painted surfaces, significantly reducing the radar return signal.[151] Unfortunately, RAM paint does not possess an unlimited electromagnetic absorption capability. Therefore, if a radar system boosts its power output, it may negate the RAM's electromagnetic field.[152] Thus it is critical to combine multiple structural methods and radar absorbent materials to reduce the RCS signature of an aircraft.

The success of new composite materials, RAM, and aircraft design in reducing the radar cross section of an aircraft is reflected in the following chart[153]:

Aircraft Type	RCS	Detectable Range
B-52H	$10m^2$	75 Km
B-1A	$1m^2$	55 Km
B-1B	$.1m^2$	30 Km
B-2	$.01m^2$	20 Km
F-117A	$.001m^2$	10 Km

Infrared signature suppression, the second characteristic of stealth, was achieved through the use of composite technology in the airframe structure as well as design features with respect to the aircraft's engine exhaust. For example, carbon composites such as carbon grain and ultradense carbon foam have superb IR dissipation characteristics.[154] The reduction of engine exhaust signatures was primarily achieved through the use of non-afterburning engines recessed into the airframe. The combination of composite technology, engine selection, and engine location, to reduce the IR signature of an aircraft was embodied in the design of F-117 and B-2. Unfortunately, all of these mechanisms serve only to reduce, not to eliminate, the heat signature of the aircraft.[155]

Acoustic signature reduction, the third stealth characteristic, is generally based on design factors to minimize the wind noise and engine noise.[156] The movement of an aircraft through the atmosphere produces a characteristic sound signature, and the design of the airframe affects that signature.[157] However, the wind noise component is not the predominant acoustic signature of an aircraft, as those who visit airports well know.

The primary contributor to the acoustic signature of an aircraft is engine noise.[158] The simplest means to reduce engine noise is the use of non-afterburning engines such as those incorporated into the F-117A and B-2. A second means of reducing engine noise is the use of a diffused noise suppressing engine nozzle to mix "cold" inlet air with "hot" exhaust air.[159] A third mechanism employed to reduce audible engine noise is to locate the engines within the fuselage.[160]

Over time, the most common method to minimize visual detection, the final stealth characteristic, has relied on the aircraft's external color, with the first attempts at camouflage occurring prior to World War I.[161] The first attempt at developing a stealth aircraft was conceived by the Austro-Hungarian Air Force in 1912.[162] The Austrian-Hungarian Air Force attempted to develop a transparent aircraft by modifying a Taube monoplane with cellophane to reduce its observability by other aircraft.[163] This attempt failed because the cellophane reflected too much

sunlight, components like the engine were still visible, and if the cellophane became wet, the aircraft became too heavy to maneuver.[164]

At the start of the 21st century, external paint schemes and camouflage patterns are still the most common methods of minimizing visual detection. Both the F-117 and the B-2 use a flat black paint scheme to minimize visual detection during their night operations. Furthermore, the employment of smokeless engines significantly reduced the ability to visually detect aircraft.

What is the effectiveness of stealth technologies in protecting aircraft from current and forecasted radar threats?

The Air Force acquired a total of 64 F-117A aircraft, including 59 production aircraft, at a cost of $6.56 billion (in FY 91 dollars), from Lockheed starting in November 1978 under the Senior Trend program.[165] Since the veil of secrecy was raised on this classified program in 1988, the F-117A flew in Operations Just Cause, Desert Storm, Southern Watch, and Allied Force.[166] The F-117A strike aircraft does not carry external stores, does not possess an active radar, but has F-404-GE-F1D2 non-afterburning engines, to enhance its stealth characteristics and represents America's first attempt at a truly stealthy fighter.[167] For the purposes of this paper, the B-2 will be postulated to incorporate even more advanced design characteristics and materials than the F-117A design. Since all stealth technology is premised on the control of four characteristics (RCS, IR, acoustic, visual) in order to minimize detection and targeting the following four issues apply to all stealth aircraft.

First, RAM paint does not possess an unlimited electromagnetic absorption capability. Therefore, if a radar system boosts its power output, it may negate the RAM's electromagnetic field.[168] Furthermore, if the integrity of the RAM coating is damaged due to factors such as

blowing sand or enroute weather, its ability to shield an aircraft from radar detection will be compromised.

Second, the low RCS an aircraft had when initially delivered to the DoD may degrade over time due to maintenance work; a "ding" to the surface by debris kicked up by a vehicle passing, during takeoff or landing; or by weather phenomena like hail.[169] Thus, changes in the RCS, when combined with damage to the RAM paint, may result in a stealthy aircraft becoming detectable to conventional radars.

The third issue is lag time. Program development cycles require the use of cutoff dates for the incorporation of technologies in aircraft design. The F-117 was approved for production in 1978 and incorporated 70's and some 80's defensive technology.[170] Thus, the stealth technologies incorporated into the F-117 twenty years ago, may not be effective against late 90's technology much less those developed and fielded in the 21st century. In light of the fact the Iraqi IADS was built upon technologies the F-117 was designed to counter, the results achieved by F-117s during Operation Desert Storm may not be achievable in future conflicts. However, current events over Serbia appear to highlight the vulnerability of the F-117A going into the 21st century.

According to Steven Komarow and Tom Squitieri, U.S. officials confirmed the F-117A lost over Serbia on March 27, 1999, was tracked by Serb military radar before it crashed.[171] Defense officials will assuredly investigate the aircraft's loss to determine if the F-117A crashed due to enemy fire or a mechanical failure. This investigation will certainly center on debriefing the pilot, who was rescued by a joint U.S. search and rescue team.[172] The loss of a stealthy F-117A in combat will focus a great deal of attention on how effective its stealth characteristics are, almost 20 years later.

The final issue surrounds the general agreement by government experts that retrofitting aircraft with stealth technology is not acceptable from either a financial or a performance standard.[173] Thus the level of stealth technology incorporated into the F-117A and B-2 inventory

will probably remain relatively static over future years due to the prohibitive costs of retrofitting past generation aircraft.

Overall, if a technological breakthrough occurs, which allows the detection and tracking of current models of stealth aircraft, the relatively slow moving F-117A and B-2 will become vulnerable to surface based threats, unless dedicated tactical jamming assets are available to support their employment.

Does execution of the Prowler's Electronic Attack mission enhance, harm, or prove irrelevant in supporting the success of stealth aircraft?

In wartime, the unexpected sometimes happens, such as maintenance access panels that come off in flight, bomb bay doors that fail to close, or an enemy SAM proves more capable than previously thought.[174] Carl von Clausewitz, a 19th century Prussian military theorist, termed occurrences such as these, the friction of war.[175] Friction is what separates a paper war from a real war and may doom the perfect plan when executed, if not planned for from the beginning.

Lieutenant Colonel Getchell, an F-117A pilot during the Gulf War, wrote that direct EF-111A Raven's jamming support was requested to support F-117A strikes against Iraqi targets during Operation Desert Storm, especially in the high threat Baghdad area.[176] The jamming of radar systems, by aircraft such as the EA-6B and retired EF-111A, reduces the sensitivity of an adversary's radar, which in turn causes the radar to lose low RCS aircraft; and thus, be unable to target low observable aircraft such as the F-117A.[177] Lt Col Getchell went on to write that the F-117A community never requested F-15 escort nor F-4G Wild Weasel HARM support indicating the importance of radar jamming to the Nighthawk's success.[178] By end of war, F-117A stealth fighters had flown 1,271 successful combat missions – with about one third of the total flown against Baghdad area targets.[179]

After the first few days of combat, the coalition discovered that radar jamming by the Ravens caused the AAA gunners to blindly fire into the air until they ran out of ammunition or overheated their barrels.[180] Therefore, during Operation Desert Storm, EF-111A Ravens were tasked to provide standoff jamming for F-117A attacks in order to elicit a poorly timed response from the hundreds of AAA guns which protected important Iraqi targets.[181] After the firing died down, strike aircraft such as F-117As and F-111Fs would then commence their attacks with a significant reduction in risk of damage from unaimed flak. Barrage AAA possesses a serious risk to any aircraft that must fly through it to attack a target – the Baghdad area alone possessed an estimated 1800 AAA guns and 60 SAM batteries.[182] Raven and Prowler radar jamming increased the Iraqi friction and fog of war by denying acquisition information to radar operators and shielding coalition air efforts from Iraqi command and control centers.

The Iraqi integrated air defense system was targeted for destruction by both precision weapons and HARMs. The possession of a large number of radar systems and spare parts however, allowed the Iraqis to reconstitute key radar installations and gain early warning of aerial attacks.[183] In addition to repairing early warning radar systems, the Iraqis were able to reconstitute numerous SAM sites by replacing acquisition and target tracking radars destroyed by HARM attacks.[184] The Iraqi ability to reconstitute the IADS required the continuous employment of radar jamming and destructive SEAD missions to ensure the success of the coalition air war. However after the Gulf War, some stealth proponents began to mislead the public on the aerial support requirements of the F-117A.

Representative Andy Ireland, House Armed Services Committee, wrote in the Christian Science Monitor, that F-117s were tracked by low frequency Chinese and French made radars inside Iraq; as well as by the US Navy's E-2C Hawkeye early warning aircraft at ranges in excess of 100 miles during Operation Desert Storm.[185] His article goes on to say that the USAF acknowledged the F-117As were escorted by USAF EF-111As and USN EA-6Bs.[186]

According to Bruce B. Auster, the USAF misled Congress by emphasizing the F-117A required no support from electronic combat planes during the war in order to justify funding of the B-2.[187] He goes on to report Air Force officials recanted that position and admitted EF-111As jammed radar systems to F-117 attacks and conducted diversionary jamming to deceive the Iraqi IADS.[188] Mr Auster also wrote that defense sources reported the ability of the US Navy's E-2C to detect the F-117 at a range of 100 miles.[189] By operating the EF-111As and EA-6Bs on a separate axis than used by the F-117s, allowed these support aircraft to distract the Iraqi air defense system.

In light of the loss of a F-117A over Serbia, it is important to note that both of these articles emphasized the vulnerability of the F-117A to detection and tracking by low frequency radars. The Journal of Electronic Defense in December 1998, reported the Yugoslav defense sales agency Yugoimport-SDPR released two upgrades to the Russian built Spoon Rest and Tall King early warning radar systems.[190] Both of these early warning radar systems are low frequency emitters and may have allowed the Serb's to detect and track the F-117A. These upgrades highlight the constant evolution of electronic attack in general and may specifically foretell the end of the Nighthawk's invincibility at night in a high threat environment.

Overall, the ALQ-99 proved effective during Operation Desert Storm and subsequent contingency operations supporting stealth and non-stealth aircraft alike. Therefore, historical data indicates the presence of the EA-6B would enhance the success of aerial operations and provide a flexible response to any ground based radar technology threat that may threaten stealth aircraft.

If future radar and computer technologies prove capable of detecting stealth aircraft, can the Prowler effectively support stealth aircraft?

Edward N. Luttwak, in his book Strategy: The Logic of War and Peace, observed the introduction of a breakthrough technology to the battlefield prompts the adversary to develop a

countermeasure in an action-reaction sequence which, in turn, will prompt the development of a countermeasure.[191] The US purchased a limited number of operational F-117s and B-2s due to the exceptionally high price tag associated with these aircraft. Based upon the tenet that stealth technology is a force multiplier, in order to pay the high price tag and in the belief that stealth aircraft would not require dedicated support assets, the USAF reduced the number of support aircraft in the inventory. If future technology is developed that is capable of detecting and tracking the F-117, B-2, or F-22, the US will possess a small force of very expensive and vulnerable aircraft. Furthermore, if the EA-6B Prowler is not maintained in the US inventory in sufficient numbers to provide Electronic Attack support to both USAF and USN contingency operations, the survivability of aircrews and aircraft in future conflicts may be jeopardized.

Lt Col Getchell wrote that the eighteen F-117s required to destroy the 36-odd aircraft shelters found in a typical Iraqi airfield could now be replaced by just two B-2s.[192] Who would be willing to risk an $800 million aircraft if it could be detected and targeted by SAMs and/or AAA? Since it is unreasonable to postulate a perfect sanctuary through stealth, some level of SEAD will be prudent into the foreseeable future.[193]

During Operation Desert Storm EF-111As supported the F-117As with electronic radar jamming. Since the EA-6B possesses capabilities similar to the EF-111A, the ability of the Prowler to support stealth aircraft is certain. Furthermore, jointly manned EA-6B units are actively supporting Operations Southern Watch and Allied Force. In fact, EA-6Bs provided jamming support to US and British aircraft striking Iraqi targets during Operation Desert Fox.[194] Thus, there is every reason to believe the EA-6B Prowler can successfully support stealth aircraft as well as conventional aircraft in future contingency operations.

In light of the critical importance of the EA-6B's capabilities to the success of contingency operations, the EA-6B's connectivity and jamming capabilities are currently being upgraded in a variety of ways. First, increased connectivity will be achieved through the incorporation of Have Quick radios and the Integrated Data Modem (IDM) into EA-6B airframes.[195] Almost all Air Force

aircraft are equipped with Have Quick radios to minimize the effects of jamming and to make the interception of transmissions more difficult. The Navy is behind the Air Force in equipping its aircraft with this radio system, but is planning to equip all of its Prowlers in the future. Currently the EA-6Bs deployed in support of overseas Air Force operations are equipped with Have Quick. However, if a contingency operation occurs that requires non-Have Quick equipped Prowlers to be used, significant connectivity concerns will arise if communications jamming is present. The second part of the connectivity improvement program pertains to the IDM, which allows the transmission of data between aircraft such as the RC-135 Rivet Joint, E-3B AWACS, F-15C, and F-16 Harm Targeting System (HTS), to enhance situational awareness while simultaneously cutting down on voice transmissions. The Navy is once again working to acquire a compatible system for its aircraft so that air operations can be more closely integrated. The enhanced situational awareness that will occur once both services are linked will decrease the potential for fratricide, increase threat avoidance capabilities for strike packages, and enhance the ability to target enemy weapon systems beyond visual range. While these connectivity issues are important and have yet to be fully resolved, operations are being conducted satisfactorily. These issues were present during Desert Storm and did not significantly impact the air campaign.

Furthermore, as reported by the Journal of Electronic Defense in April 1998, the Prowler's ALQ-99F is being upgraded through the Improved Capabilities III program with new receivers and exciters to increase the jamming capability of the Prowler and enhance system reliability to meet future radar threats.[196] This $144.2 million contract will allow the upgrade of the 120 EA-6Bs in the Navy inventory, which includes the aircraft of the four Joint Expeditionary Squadrons manned by the USAF and USN.[197] Additionally, Lockheed Martin Company was awarded a $12.9 million contract to build 33 new USQ-113 (V) 2 Phase III tactical communications jammers and upgrade 30 existing USQ-113s to enhance EA-6Bs communication jamming capabilities.[198] The USQ-113 upgrade is scheduled for completion by August 2000.[199]

Overall, the EA-6B possesses the capabilities necessary to continue to successfully support stealth and non-stealth aircraft in contingency operations. The critical issue for the future, however, is the service life of the current EA-6B Prowler fleet, which is estimated to end in 2015.[200]

Finally, if the US acquires a truly stealthy aircraft, will the US still require the successful execution of the EA mission to conduct contingency operations?

The EA-6B Prowler will be necessary, not only to facilitate the success of non-stealth aircraft, but to support stealthy aircraft as the friction of war wears down forces. For stealth aircraft, the friction of war can encompass factors such as maintenance panels that open in flight, the deterioration of the RAM coating over time or due to weather, or weapons bay doors that are required to be open for weapons delivery that fail to close after release. Furthermore, stealth aircraft, especially small fighter-size aircraft, will still need to refuel from tankers, receive air and electronic order of battle updates from AWACS or RIVET JOINT aircraft, and work in concert with non-stealthy aircraft that are all susceptible to radar detection and tracking.

Tankers generally do not operate in a high threat environment, but their presence indicates refueling activities, which may key an adversary's IADS search system or provide warning of an impending attack unless the appropriate part of the IADS is suppressed. Furthermore, for aircraft required to emit electromagnetic energy to fulfill their mission, such as the United States Navy's E-2C (Airborne Early Warning), as well as the United States Air Force's E-3B (Airborne and Early Warning System) and E-8 (Joint Surveillance, Tracking, and Acquisition Radar System), the mission requirement to emit negates the stealth concept.[201] All of these aircraft are limited, expensive, high value assets that act as a tremendous force multiplier to combat commanders. As Mr Chun pointed out, the high cost of stealth technologies makes it questionable whether stealth technology should be applied to all future aircraft such as transports, AWACS, and maritime

patrol.[202] Thus, the protection of limited high value aircraft is aided by screening their presence from an adversary's early warning radar systems via electronic radar jamming.

This screening function not only serves to protect high value assets, but also hinders an enemy's ability to predict our intentions by masking the buildup of coalition aircraft prior to ingress. Minimizing an adversary's reaction time directly contributes to the survivability of aircrews and aircraft as well as mission success. Since the US is likely to conduct aerial operations in concert with allied Air Forces represented by NATO or future coalition partners, the aerial assets of our partners may need to be screened in order to protect their participation in an aerial conflict or to minimize warnings and indications to an adversary of the combined effort.

Jamming can also be effective at all times – unlike a HARM, which possesses finite utility. Once a HARM is fired it will strike the emitting target or go ballistic if the emitter goes off the air prior to the HARM reaching the target. In either case, the HARM must wait for an emitter to activate, then fly through the air, all while the radar is developing the "air picture." If the emitter only activates for a few sweeps to develop the air picture and then goes down, the enroute HARM shot is neutralized and the radar survives to be employed another day. Therefore, the unpredictability of radar employment requires the continuous suppression capability inherent in a radar jammer to protect aircraft in a hostile environment.

A third reason the Electronic Attack mission will be viable in the future is that stealth technology is not really appropriate for the Close Air Support (CAS) mission. This mission takes place day or night, low to the ground, and within close proximity to friendly and hostile forces. This makes the CAS sortie a high visibility mission versus Strategic Attack or Counter Air. Therefore, to invest millions of dollars in aircraft whose mission centers on flying within visual range of enemy ground forces would not be practical.

A final reason for the continuance of the Electronic Attack mission exemplified by the Prowler focuses on the requirement to provide escort and support to Combat Search and Rescue (CSAR) forces. These forces are now composed of helicopters and in the future may consist of the

tilt-rotor Osprey. These airframes may need radar jamming to mask their ingress and egress in a hostile environment to facilitate the survival of the rescue forces as well as the retrieval of the downed airman.

Overall, the result of US reliance on aircraft that emit electromagnetic energy to perform their mission, the employment of tankers, the need to support coalition assets, the inapplicability of stealth to the CAS mission, and the possible requirement to support CSAR efforts, the US will need to continue to field a tactical radar jamming platform that can respond across the spectrum of EA requirements.

Conclusion

Retention of the Prowler is Key to Future Flexibility

"In war the best strategy is always to be strong."[203]

Carl von Clausewitz

History repeatedly demonstrated man's ability to develop countermeasures to new weapon systems. The birth of radar reflected this trend, in that radar was developed to counter a growing air threat. The British developed the first integrated air defense system during the 1930's by networking radar sites along their eastern coastline to provide early warning of air attacks from the continent of Europe with Fighter Command.[204] The significant contribution radar made to the successful defense of Britain in 1940 resulted in the recognition that the means to defeat this system also needed to be found if a successful strategic bombing campaign was to be conducted. Thus, World War II witnessed the development of the modern theory of Electronic Warfare and dedicated tactical radar jammers.

Today, the proliferation of modern surface-to-air missile systems, early warning and acquisition radars, and anti-aircraft artillery weapon systems require a robust Electronic Attack capability. Even though the stealthy F-117, B-2, and F-22 garner a great deal of attention, these aircraft represent a small percentage of the United States aerial arsenal. Therefore, the United States will continue to need an EA platform to provide tactical jamming support to non-stealthy aircraft in a medium-to-high threat environment in a joint or combined operation. Furthermore, the loss of an F-117A over Serbia may highlight the vulnerability of stealth technology to new countermeasures, necessitating tactical radar jamming support by stealth aircraft during future conflicts.

With the retirement of the EF-111A Raven, the EA-6B Prowler is the only platform capable of jamming tactical radar threats. The debate on retiring or maintaining the EF-111A was

very energetic and focused on five key areas: the existence of 127 EA-6Bs versus 40 EF-111As, costs of $3,255 versus $5,500 per hour for the EA-6B and EF-111A respectively, the inability to fund upgrades for both aircraft do to fiscal constraints, the possession of the USQ-113 tactical communications jamming system by the EA-6B, and the proposal that the EA-6B's larger crew enhanced situational awareness.[205] While all of these elements are true and General Powell clearly articulated that the EF-111A and EA-6B provided complimentary support not duplicative, the final decision to retire the EF-111A was a pragmatic business decision based on fiscal limitations. Going into the 21st century, the successful integration of EA-6Bs into joint and combined operations will have significant impact on the survival of aircrews and aircraft as history has repeatedly proven in the age of radar directed threats. This monograph explored the necessity for maintaining the Electronic Attack radar jamming mission, exemplified by the EA-6B, in the stealth age and found this mission will remain critical to the success of stealthy and non-stealth aircraft alike.

Despite the fact the service life of the current EA-6B Prowler fleet is estimated to end in 2015, force modernization programs will ensure the retention of modern EA capabilities until retirement actually occurs.[206] The modernization of the EA-6B weapon system with the Multipurpose Advanced Tactical Terminal and the Integrated Data Modem will increase the situational awareness and national intelligence resources available to the aircrew.[207] Furthermore, upgrades to the ALQ-99F through the Improved Capabilities III program will improve reliability and enhance the radar jamming capabilities of the EA-6B through the incorporation of new receivers and exciters.[208] Additionally, the Lockheed Martin Company was awarded a $12.9 million contract to build or upgrade 63 USQ-113 (V) 2 Phase III tactical communications jammers to enhance the EA-6Bs communication jamming capabilities.[209] The USQ-113 upgrade is scheduled for completion by August 2000.[210]

Moreover, the ALQ-99F provides the Prowler with a superb built in radar warning receiver, enhancing its ability to detect radar-guided threats. This capability not only allows the

Prowler to maneuver to avoid radar threats but to pass threat calls to the strike package so they can maneuver to avoid becoming engaged. This electronic capability significantly enhances the survivability of limited number of aircrews and the success of the mission. Therefore, the EA-6B prowler will certainly be a modern platform and credible force multiplier into the 21st century. In light of the Prowler's scheduled retirement in 2015 however, the requirement for a follow-on system is a must.[211] While the EA-6B is needed, future threat technologies may require additional capabilities to complement the Prowler's capabilities.

Two recommendations can be made based on the research findings of this monograph. First, the Department of Defense also needs to develop and fund a follow-on non-destructive SEAD platform in order to retain the ability to protect stealth aircraft against the principal threat — radar — after the EA-6B is retired. Long program lead times require this emphasis to occur immediately. Sensor technology will undoubtedly improve as new technologies are developed in the future, which may minimize the utility of current stealth technologies and in turn, drive up the cost of developing and integrating future stealth technologies. Currently, the US Air Force and the Defense Advanced Research Projects Agency (DARPA) are involved in a three year effort called the Advanced Tactical Targeting Technology (AT^3) program to build the Air Force's next generation destructive SEAD system.[212] One approach to be studied is the use of an Unmanned Combat Aerial Vehicle (UCAV) incorporating stealth technologies and capable of performing the destructive SEAD mission.[213]

Secondly, while acknowledging the importance of incorporating stealth technologies in future airframes, the DoD must publicly acknowledge that no aircraft will be "invisible" across the entire radio frequency spectrum. This position statement is critical if a follow-on to the EA-6B's radar jamming capability will be given priority and programmed into future defense expenditures.

The ability of the Navy's EA-6Bs to support United States contingency operations is of paramount importance in light of the fact that the United States provided 96 percent of the coalition's electronic warfare assets during Desert Storm.[214] The retirement of the EF-111A

requires the Navy to be able to respond anywhere in the world, on short notice, to support Air Force and possibly coalition operations. If the Navy is unable to meet contingency requirements in peacetime without planning to strip assets from preplanned operations, then the Navy's ability to support actual wartime requirements would become highly questionable.

The US military's ability to dominate the electromagnetic spectrum through the effective synchronization of electronic warfare assets is central to the success or failure of our military operations.[215] The radar threat of the 1990's and our heavy reliance on conventional, non-stealthy aircraft will continue to require the United States to maintain a strong tactical radar jamming capability. In light of fiscal constraints and past Department of Defense decisions, the effective employment of Electronic Warfare is now clearly a joint mission.

Keep in mind what General Curtis LeMay said on June 15, 1984:

> "To commit the youth of our nation to lay their lives on the line, we must at least take the viewpoint to equip them with the best weapons that time and technology can provide, and provide them with military leaders who are trained and encouraged to pursue the most innovative approaches to operations and tactics. With these elements in place, the remaining task is to train, train, train, under the most realistic conditions that can be imposed for the military operations that appear most likely."[216]

The continuing presence of a tactical radar jamming capability, such as possessed by the EA-6B, provides the mechanism through which breakthroughs in stealth detection and tracking can be countered in a flexible and timely manner. The creation of the Joint Expeditionary Squadrons, in light of the Air Force's decision to retire the EF-111A, is but the first step in an innovative approach to joint dependency. Cooperative training, modernization, and improved connectivity of the EA-6B fleet will be the keys to successful joint operations in the future. Limited assets and the years it takes to develop an experienced aircrew member require that the system works right the first time—there may not be the time or resources to relearn past lessons.

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